12

AMMRC CTR 77-19

STUDIES OF TEXTURE DEVELOPMENT IN STEEL ARMOR PLATE

July 1977

By Hsun Hu

United States Steel Corporation
Research Laboratory
Monroeville, Pennsylvania 15146

Final Technical Report
Contract Number DAAG46-77-C-0014

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Prepared for

ARMY MATERIALS AND MECHANICS RESEARCH CENTER
Watertown, Massachusetts 02172

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Table of Contents

	Page
Foreword	ii
List of Tables	iii
List of Illustrations	iv
Abstract	1
Introduction	2
Materials and Procedures	4
Steel Composition and Ingot Dimensions	4
Hot Rolling Procedures	5
Material for the 6- by 12- by $\sim$1/2-Inch Plates Having (112) + (111) Texture	5
Exploratory Specimens for Producing Nearly (111) Texture by Quenching Cross-Rolled Austenite	9
Results and Discussion	10
Texture of the 6- by 12- by $\sim$1/2-Inch Plates	10
Microstructure and Hardness of the 6- by 12- by $\sim$1/2-Inch Plates	11
Ballistic Performance of the 6- by 12- by $\sim$1/2-Inch Plates	13
Texture of the Cross-Rolled Specimens	14
Microstructure and Hardness of the Cross-Rolled Specimens	16
Summary and Conclusions	17
Future Work	18
Acknowledgements	18
References	19
Appendix A	

FOREWORD

This report was prepared by the Research Laboratory of United States Steel Corporation under U. S. Army Contract No. DAAG-46-77-C-0014. The contract was administered by the U. S. Army Materials and Mechanics Research Center, Watertown, Massachusetts, Anthone Zarkades-Contracting Officer Representative. This is a final report and covers work conducted from January 20 to June 20, 1977.

List of Tables

Table	
I	Chemical Composition of Armor Steel in Weight Percent
II	Hardness of the Plates Rolled to Various Reductions at 1500°F then Quenched and Tempered
III	Ballistic Performance of the Plates Rolled to Various Reductions at 1500°F then Quenched and Tempered. Texture Type (112) + (111)
IV	Summary of Information on Exploratory Specimens Cross-Rolled to Various Reductions at 1500°F then Quenched and Tempered

List of Illustrations

Figure

1 (110) Pole Figures of the Plates Rolled to Various Reductions at 1500°F then Quenched and Tempered (Ingot 705). A. 60%; B. 70%; C. 80%; and D. 90%.

2 (200) Pole Figures of the Plates Rolled to Various Reductions at 1500°F then Quenched and Tempered (Ingot 705). A. 60%; B. 70%; C. 80%; and D. 90%.

3 Microstructure of the Plate Rolled 60% at 1500°F then Quenched and Tempered (Ingot 705). Nital Etch. X500.

4 Microstructure of the Plate Rolled 90% at 1500°F then Quenched and Tempered (Ingot 705). Nital Etch. X500.

5 Correlation of the Ballistic Limit with the Intensity of (112) + (111) Texture.

6 (110) Pole Figures of the Specimens Cross-Rolled to Various Reductions at 1500°F then Quenched and Tempered. A. 60%; B. 70%; C. 80%; and D. 90%.

7 (200) Pole Figures of the Specimens Cross-Rolled to Various Reductions at 1500°F then Quenched and Tempered. A. 60%; B. 70%; C. 80%; and D. 90%.

8 (222) Pole Figure of the Specimen Cross-Rolled 90% at 1500°F then Quenched and Tempered.

9 Microstructure of the Specimen Cross-Rolled 60% at 1500°F then Quenched and Tempered. Nital Etch. X500.

10 Microstructure of the Specimen Cross-Rolled 90% at 1500°F then Quenched and Tempered. Nital Etch. X500.

Studies of Texture Development in Steel Armor Plate

by

Hsun Hu

Abstract

The present research program consisted of two parts. (1) To produce a number of 6- by 12- by ~1/2-inch armor plates having strong (112) + (111) texture with various degrees of intensity by the thermomechanical processing treatments of essentially the same medium-carbon, 5Ni-Si-Cu-Mo-V steels used previously, and to establish the reproducibility of texture, microstructure, hardness, and ballistic performance of these steel armor plates. Results indicated that the reproducibility of the structure and properties of these steel armor plates was excellent. The ballistic limit increased with the texture intensity in nearly the same manner as observed previously. (2) To explore the possibility of producing a nearly (111) texture with various degrees of intensity in small-size specimens cross-rolled at 1500°F to various reductions then quenched, and to establish a procedure for optimizing this texture in larger 6- by 12- by ~1/2-inch plates. Results indicated that the texture obtained was {223}⟨032⟩, which is about 11 degrees from {111}⟨011⟩, close to that predicted. The development of this texture should be possible in larger 6- by 12- by ~1/2-inch plates that can be used for the testing of mechanical and ballistic properties.

Introduction

Results from a recent investigation[1)]* on the effect of crystallographic texture on the ballistic performance of a medium-carbon 5Ni-Si-Cu-Mo-V steel indicated that the V_{50} ballistic limit of the (112) + (111) textured plates was substantially higher than that of random-textured plates at approximately the same hardness. Furthermore, the improvement in the ballistic limit increased with the texture intensity. To assure reproducibility of the results, and to enable more extensive studies with these textured plates, it would be desirable to produce a number of additional 6- by 12- by 1/2-inch armor plates with various degrees of the (112) + (111) texture. These plates could be used for a variety of additional studies of the mechanical and ballistic properties not comprehended in the earlier investigation[1)] so that such textured plates could be fully characterized.

It is well known that the Young's modulus, E, of iron or steel is the highest in the [111] direction,[2)] and that the stress intensity of the reflected tensile wave upon impact deformation is proportional to $E^{1/2}$,[3)] whereas the cleavage stress if roughly proportional to E.[4)] Thus, a strong (111) texture in the plane of the plate may further improve the ballistic performance of the plate. From the available data on the texture behavior of common

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*See References.

fcc metals, and the orientation relationship of austenite to martensite in steels, it appears feasible to produce a nearly (111)-textured steel armor plate by appropriate thermomechanical processing treatments.

As is well known, the orientation relationship between the austenite and the martensite resulting from phase transformation is that of the Kurdjumov-Sachs,[5] which has 24 crystallographically equivalent variants. These can be expressed in the generalized form:

$$\{111\}_\gamma \parallel \{110\}_\alpha \quad \langle 111\rangle_\gamma \parallel \langle 110\rangle_\alpha$$

or

$$\langle 110\rangle_\gamma \parallel \langle 111\rangle_\alpha \quad \{110\}_\gamma \parallel \{111\}_\alpha$$

since, for cubic lattices, the indices of planes and directions are identical. Thus, to produce a plate nearly (111) oriented in the plane of the plate (or a [111]-textured plate with a [111] axis normal to the plate), a strongly (110)-oriented austenite will have to be produced. It was recently shown by Davies et al.[6] that such orientation-related transformation textures can be predicted satisfactorily without variance selection by using the crystallite orientation distribution functions of Roe.[7]

Some time ago Merlini and Beck[8] showed that the texture of heavily cross-rolled copper is predominantly (110)[2$\bar{2}$3]. The same kind of cross-rolling texture should be developed, and was observed, in fcc alloys of low stacking-fault energies, such as the 70-30 brass.[9] Thus, heavy cross rolling of the armor steel in the

austenite region without concurrence of recrystallization, for example at 1500°F (816°C), should develop a strong (110) texture in the plane of the plate. Upon immediate quenching of the cross-rolled austenite, it should be possible to produce a strongly (111)-textured martensite in the armor plate.

The present research program, under a five-month interim contract awarded by the Army Materials and Mechanics Research Center to the United States Steel Research Laboratory (Contract No. DAAG-46-77-C-0014), consisted of two parts: (1) To produce a number of 6- by 12- by ~1/2-inch armor plates having a strong (112) + (111) texture with various degrees of intensity, and to check the reproducibility of earlier results in texture, microstructure, hardness, and ballistic properties; and (2) to explore the possibility of producing a strong (111) texture with various degrees of intensity in small-size specimens, and to establish a procedure for optimizing this texture in 6- by 12- by ~1/2-inch plates.

Materials and Procedures

Steel Composition and Ingot Dimensions

For the first part of the research program, namely, to produce a number of 6- by 12- by 1/2-inch armor plates having a strong (112) + (111) texture of various intensities and to establish the reproducibility of earlier results, three 500-pound (227 kg) heats of nominally the same chemical composition as that of the steel used previously,[1] were vacuum-melted and cast at the Laboratory. The ingots, one from each heat, were of the same dimensions

as those in earlier investigations, 7 by 12 by 24 inches (180 by 300 by 600 mm). Check analyses of samples taken from the hot-rolled plates, 0.55 inch (14 mm) thick, are shown in Table I. Within narrow variation limits, these compositions matched closely with those of earlier steels.[1)]

For the second part of the present program, that is, to explore the possibility of producing a strong (111) texture with various degrees of intensity in small-size specimens, some of the trimmed-off edge material from the intermediate plates (2-1/8-in. thick) left over from the earlier investigation[1)] was used.

Hot-Rolling Procedures

Material for 6- by 12- by ~1/2-Inch Plates Having (112) + (111) Texture. For producing the (112) + (111) textured plates of various intensities, the preliminary hot rolling of the ingot to the various intermediate thicknesses and the final isothermal rolling to a common plate thickness after various reductions were conducted in exactly the same manner as described previously.[1)] However, some minor modifications were employed for one or all three ingots in the method of cooling of the intermediate pieces and in the reheating temperature for final isothermal rolling. These modifications were adopted mainly to improve the processing conditions, and produced no significant effects on the texture and properties.

For preliminary hot rolling to the various intermediate thicknesses, namely 5.50, 2.75, 1.85, and 1.40 inches (140, 70, 47, and 36 mm), the ingots were hot-charged into a preheating furnace

at 2250°F (1230°C), soaked for two hours, and then rolled from the 7 inches of the ingot thickness to a sl b of 5.50 inches. A predetermined length was torch-cut from the bottom end of the slab, and the remaining slab was then reheated to temperature in the furnace. After about 15 to 20 minutes reheating, the slab was again rolled to the next intermediate thickness (2.75 inches) and another predetermined length was torch-cut from the previously cut end of the piece. The reheating, hot-rolling, and torch-cutting procedures were repeated until the piece was finally rolled to 1.40 inches in thickness.

For the first two ingots (No. 705 and 706, Table I), these intermediated pieces were all cooled in air, the practice employed in the previous investigation.[1)] When the intermediate pieces were later cut by abrasive cut-off wheel along the midwidth line so that each piece became two 6-inch-wide halves, hairline cracks were always observed on the cut-off faces. As will be described later, these hairline cracks may have been responsible for some edge cracking during the next rolling. To control the temperature in final rolling, a small hole (5/32 inch or 3 mm in diameter) for insertion of a thermocouple was drilled in each piece on the cut-off face at approximately the midposition of thickness and width by electrical discharge machining (EDM), because the material was too hard to be drilled in an ordinary drill press.

The hairline cracks and the high hardness of the intermediate pieces indicated that the steel was practically hardenable

by cooling in air, and that the volume change in phase transformation was probably responsible for the hairline cracks observed on the cut-off faces. It was noted that in the finally rolled and quenched plates some edge cracking (mostly about 0.5 inch in length) occurred on the prior cut-off side of the intermediate pieces. This suggested that the hairline cracks in the intermediate pieces had induced edge cracking in the final plates.

In an attempt to eliminate the hairline cracks in the intermediate pieces, hence the occurrence of some edge cracking in the final plates, the intermediate pieces from the third ingot (No. 717) were cooled in vermiculite. No hairline cracks were observed on the cut-off faces and the thermocouple holes were drilled in an ordinary drill press without difficulty. It was obvious that cooling the steel slowly in vermiculite resulted in the formation of the high-temperature transformation products together with some tempered martensite and bainite in the intermediate pieces.

In the final rolling treatment, the intermediate pieces from all three ingots were reheated for two hours at 1650°F (900°C)*, rolled isothermally at 1500°F (816°C) to a final thickness of 0.55 inch (14 mm), and water-spray-quenched to room temperature. This procedure resulted in reductions in thickness of 60 to 90 percent

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*This reheating temperature was slightly lower than that used previously (1700°F). It was adopted purposely to reduce the cooling time required to the isothermal rolling temperature of 1500°F. For the slowly cooled intermediate pieces of Ingot 717, this reheating time and temperature were found adequate to reausteniitize the steel.

for the intermediate pieces 1.40 to 5.50 inches thick, respectively. As was the case in the previous investigation,[1] for the intermediate pieces of small thicknesses (1.40 and 1.85 inches) no difficulty was encounte cooling the piece on the run-off table from the reheating temperature of 1650°F to the isothermal rolling temperature of 1500°F before starting to roll. Isothermal conditions were closely approximated by using a predetermined program of varying amounts of reduction per pass so that the heat lost by radiation and convection was nearly balanced by the heat generated during deformation. For the more massive pieces (2.75 and 5.50 inches thick), it was necessary to start rolling at a somewhat higher temperature than the desired isothermal rolling temperature of 1500°F (rolling started at around 1575 and 1600°F as indicated by the inserted thermocouple) so that the corners and edges of the piece would not be cooled excessively in comparison with the interior, resulting in nonuniform deformation or severe difficulties in the rolling operation. However, the somewhat higher start-rolling temperature was gradually reduced to the desired rolling temperature in the first few passes. The slightly lower reheating temperature used in the present investigation, hence shorter waiting time for start of rolling, should have assisted in attaining more uniform deformation in the final plates.

Whereas the plates from the first two ingots (No. 705 and 706) showed some edge cracking on the prior cut-off side of the intermediate pieces, those from the third ingot (No. 717) were free

from such defects. The slower cooling rate (cooled in vermiculite vs in air) applied to the intermediate pieces of the third ingot was apparently responsible for this improvement.

<u>Exploratory Specimens for Producing Nearly (111) Texture by Quenching Cross-Rolled Austenite</u>. Small blocks having dimensions of approximately 1.5 by 1.5 by 0.5 or 1.0 inches (∿38 by 38 by 13 or 26 mm) were cut off from the edge material left over from the earlier investigation. The 0.5-inch-thick blocks were used for cross rolling to 60 and 70 percent reductions in thickness, whereas the 1.0-inch-thick blocks were used for 80 and 90 percent reductions. The final thicknesses of these exploratory specimens produced for texture, microstructure, and hardness examinations were thus 0.20 to 0.10 inch (5.1 to 2.5 mm).

For isothermal cross rolling at 1500°F, the steel block was heated in a preheating furnace at 1700°F and held at temperature for 15 minutes. The piece was then transferred to another furnace set at 1500°F. When the specimen reached this temperature, it was taken out and rolled in the first rolling direction (designated as RD_1) with a predetermined amount of reduction. The specimen was put back into the furnace to restore the temperature. For the second rolling pass, the specimen was rotated 90 degrees from the initial orientation before entering the rolling mill. The amount of reduction in the second rolling direction (designated as RD_2) was the same as in the previous pass in the first rolling direction. These procedures were then repeated until the final

thickness was reached. The total reduction in RD_1 and RD_2 was made the same in each specimen. Immediately after the final pass in RD_2, the specimen was quenched in water.

As a standard practice in the previous and present investigations, all the quenched materials were given a tempering treatment of 1 hour at 350°F followed by cooling in air before examinations for structure and properties. For ballistic tests, the tempered plates were surface-ground to 0.5 inch or less in thickness to remove oxide scale and decarburized material in the subsurface layers. Sixty-six 6- by 12- by ∿1/2-inch plates, identified in Appendix A, were shipped to the Army Materials and Mechanics Research Center for ballistic testing and other mechanical and metallographic studies by the Army.

Results and Discussion

Texture of the 6- by 12- by ∿1/2-Inch Plates

The crystallographic textures of the plates were examined by X-ray pole figures determined from the midthickness section. Specimens of plates rolled to various reductions from the three ingots were all examined. For the first two ingots (No. 705 and 706), both the (110) and (200) pole figures were determined by the Schulze reflection technique up to a tilt angle of 80 degrees from the rolling-plane normal, using filtered MoK_α radiation. For the third ingot (No. 717), only the (110) pole figures were determined. The nature and degree of intensity of the textures were similar to those in the plates processed in the earlier investigation.[1]

In fact, the intensity maxima, as shown by the (110) pole figures of the present plates, particularly those rolled to high reductions, were appreciably higher than those observed previously. The reason for this observed increase in texture intensity for the present plates is not clear. The somewhat higher inclusion contents (as shown by the microstructures to be described in the next section), which could be an indication of higher oxygen contents actually present in the steels, may have retarded the rate of recovery during hot rolling; this resulted in higher X-ray diffraction intensity.

In Figures 1 and 2, the (110) and (200) pole figures, respectively, of the plates rolled 60 to 90 percent from Ingot 705, are presented. Those of correspondingly rolled plates from Ingot 706 or 717 were quite similar except that the intensity maxima were somewhat lower. As can be noted from these pole figures, the nature of the texture was a strong (112) + (111); and the texture intensity, as indicated by the average intensity maxima of the (110) pole figures, increased with rolling reduction from 3.75 at 60 percent reduction to 9.05 at 90 percent reduction.

Microstructure and Hardness of the 6- by 12- by ∿1/2-inch Plates

The microstructures of the 6- by 12- by ∿1/2-inch plates rolled to various reductions from the three ingots were examined on the longitudinal and transverse sections by light microscopy. In accordance with previous observations, the structure is all martensitic and consists of bands lying nearly parallel to the rolling plane, elongated most prominantly in the rolling direction.

Figures 3 and 4 show the photomicrographs of the plates rolled 60 and 90 percent, respectively, of Ingot 705. The plates rolled to 70 and 80 percent reductions had similar structural features, as did the corresponding plates from the other two ingots (No. 706 and 717). Such structural bands were believed to represent the textural components and not the reduced thicknesses of the prior austenite grains after rolling reductions.[1)] The thickness of the structural bands was nonuniform, and the average band thickness appeared to decrease slightly with increasing reduction.

Upon examination of the microstructures of the various plates rolled from the present three ingots, it was noticed that the inclusions were apparently more numerous than in the steels used in the previous investigation.[1)] These inclusions were particularly evident when the polished surfaces were examined before etching. Even on the etched surfaces, such as the photomicrographs shown in Figures 3 and 4, scattered dark patches where inclusion particles were located can be noticed. However, these structural features were not indicated by the results of chemical analysis (Table I), except for the unusually high oxygen content reported for one of the samples (Footnote under Table I).

The hardness of the various plates was measured on the metallographic specimens. Ten measurements of the DPH numbers were made (5 on the longitudinal and 5 on the transverse sections) for each plate. The average values of these measurements, converted to the R_C scale, are shown in Table II. The hardness values measured

on the longitudinal section of the specimens were slightly but consistently higher than those on the transverse section, suggesting anisotropy due to preferred orientations. These hardness values agree well with those observed for the armor-steel plates processed previously.[1)]

Ballistic Performance of the 6- by 12- by ~1/2-inch Plates

One plate for each rolling reduction from each of the three ingots processed was tested for the V_{50} ballistic limit with 0.50 caliber projectiles at zero degree obliquity. The results, together with the texture intensity, hardness, and thickness of the plates, are summarized in Table III.

It was recently suggested by K. H. Abbott[10)] of AMMRC that the ballistic data of textured plates obtained in the previous investigation[1)] could be shown more meaningfully as a function of texture intensity, including random-textured plates (texture-intensity parameter being equal to 1.00), after corrections were made to a uniform plate thickness. The thickness correction factor was 10 fps in ballistic limit per 0.005 inch of plate thickness (taken from MIL S-12560). Abbott showed that the corrected ballistic limit had a linear dependence on the texture intensity, with a scatter band of about 100 fps on either side of the mean ballistic limit, which is roughly equivalent to a standard deviation of $\sigma = 30$. As pointed out by Abbott, this is an important point because ballistic-limit data that have been subjected to statistical analysis by the Test and Evaluation Command at APG for homogeneous

steel armor of "uniform good quality" against the caliber 0.50 APM2 at 0° obliquity had a standard deviation on the order of 30 fps.

Following the same procedures for plate-thickness corrections, the V_{50} ballistic limits of the present textured plates were plotted against the texture-intensity parameter. The results are shown in Figure 5 together with the ballistic test results of previous investigations after corrections for plate thickness. Most of the data points are within the scatter band. Only a few data points fall slightly outside the band, indicating somewhat wider scatter of the textured plates. However, the trend for the ballistic limit to increase substantially with the intensity of the (112) + (111) texture is clearly indicated by these results.

As observed previously, back spalling appears to occur frequently in strongly textured plates upon ballistic testing. Structural banding along the thickness direction and parallel to the rolling plane of the plate (see Figures 3 and 4), which is believed to be associated with the texture components present in the plate, may have been responsible for the low back-spalling resistance of the textured plates.

Texture of the Cross-Rolled Specimens

The crystallographic texture of the small-size specimens cross-rolled to various reductions at 1500°F then quenched and tempered were examined on the midthickness section. Figures 6 and 7 show, respectively, the (110) and (200) pole figures. As

expected from cross rolling to nearly equal strains in both rolling directions (RD_1 and RD_2), the pole figures show approximately the same symmetry with respect to either rolling direction even though the texture, as shown, is that of the martensite transformed from the cross-rolled austenite.

As a consequence of this apparently high symmetry of the pole figures, one may easily be misled to a first impression that the texture is of a (100) or (110) type since the rolling plane has a four-fold or a two-fold symmetry with the reflection planes. That the texture of these cross-rolled specimens actually had a high concentration of approximately (111) planes in the plane of rolling is shown more convincingly by the (222) pole figure in Figure 8. The texture is mainly $(223)[03\bar{2}]$, which is only about 11 degrees from $(111)[01\bar{1}]$ with respect to either of the two rolling directions. Hence, the prediction of the texture of the martensite that is produced by transformation of cross-rolled austenite, based simply on the Kurdjumov-Sachs orientation relations, was confirmed.

The intensity of the texture of all these cross-rolled specimens was low. This is believed to be due to the reheating of the specimen between passes during rolling, a procedure necessary for isothermal rolling of small-size specimens. It is obvious that during this reheating extensive recovery, and hence a reduction in the dislocation density, occurs. Consequently, as the perfection of the crystallites increases, the intensity of the diffracted X-ray decreases because of increased primary extinction.

When the isothermal condition can be controlled in rolling larger pieces, such as the 6- by 12- by ∿1/2-inch armor plates, the intensity of the texture should be substantially increased. Even with the relatively low texture intensities of the present cross-rolled specimens, the intensity of the texture showed increases with rolling reduction (see Table IV).

<u>Microstructure and Hardness of the Cross-Rolled Specimens</u>

The microstructures of the two cross sections of the small-size specimens cross-rolled to 60 and 90 percent reductions in thickness are shown in Figures 9 and 10, respectively. As a consequence of the approximately equal amount of reduction in each of the two orthogonal rolling directions, the microstructures of the two cross-sections are almost indistinguishable. The structural banding, even in the specimen cross-rolled 90 percent (Figure 10), is much less markedly defined than in the straightaway-rolled specimen (Figure 4). As was postulated earlier, the low resistance to back spalling in strongly textured armor plates (produced by straightaway rolling to high reductions then quenched and tempered) is believed to be due to the structural or textural banding.[1)] It would therefore be interesting to see whether the heavily cross-rolled 6- by 12- by ∿1/2-inch plates, when produced in the future, would show higher resistance to back spalling upon ballistic testing.

The hardness and other technical information of the cross-rolled specimens is summarized in Table IV. The average hardness

of the cross-rolled specimens appears to be somewhat higher than that of straight-rolled 1/2-inch-thick armor plates at the same amount of rolling reduction. However, these differences may have been a consequence of effective quenching because the thicknesses of the cross-rolled exploratory specimens (0.10 to 0.20 inch) were substantially less than those of the 1/2-inch-thick armor plate.

Summary and Conclusions

The first part of the present research program was to produce a number of 6- by 12- by ∿1/2-inch armor plates having strong (112) + (111) texture with various degrees of texture intensity by the thermomechanical processing treatments of essentially the same medium-carbon, 5Ni-Si-Cu-Mo-V steels as used previously,[1)] and to establish the reproducibility of texture, microstructure, hardness, and ballistic performance of these steel armor plates. Results indicated that these structures and properties of the present plates were all comparable to those reported previously. In agreement with the earlier findings,[1)] the ballistic limit of the present plates increased with the intensity of the (112) + (111) texture. When the observed ballistic limits of all the plates, including those with nearly random texture, were corrected to a common plate thickness, the corrected ballistic limit data nearly all fell within a scatter band of ± 100 fps. The median of the scatter band, which increases linearly with the texture intensity, thus corresponded to a standard deviation of roughly ± 30 fps.

For the second part of the present program, that is, to explore the possibility of producing a nearly (111) texture with various degrees of intensity in small-size specimens cross-rolled at 1500°F to various reductions then quenched and tempered, the textures produced were {223} ⟨032⟩, which is close to (about 11 degrees from) the predicted {111} ⟨011⟩ texture.

Future Work

Results from the second part of the present investigation indicate that a nearly (111) texture with various degrees of intensity can be produced by isothermal cross rolling at 1500°F to various reductions in thickness then quenched. To produce 6- by 12- by ~1/2-inch armor plates with this texture and to study their structure, mechanical properties, and ballistic performance in future investigations should prove worthwhile.

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References

1. H. Hu, G. R. Speich, and R. L. Miller: "Effect of Crystallographic Texture, Retained Austenite, and Austenite Grain Size on the Mechanical and Ballistic Properties of Steel Armor Plates," AMMRC CTR 76-22, July 1976, Contract No. DAAG46-75-C-0094.

2. E. Schmid and W. Boas: Plasticity of Crystals, Hughes and Co., Ltd., London, 1950.

3. N. Goldsmith: The Theory and Physical Behavior of Colliding Solids, E. Arnold, London, 1960.

4. A. Kelly: Strong Solids, Clarendon Press, Oxford, 1966.

5. G. Kurdjumov and G. Sachs: Z. Physik, 1930, Vol 64, pp 325-343.

6. G. J. Davies, J. S. Kalland, and P. P. Morris: "The Quantitative Prediction of Transformation Textures," Acta Metallurgica, 1976, Vol 24, pp 159-172.

7. R. J. Roe: "Description of Crystallite Orientation in Polycrystalline Materials, III, General Solution to Pole Figure Inversion," Journal of Applied Physics, 1965, Vol 36, pp 2024-2031.

8. A. Merlini and P. A. Beck: "Study of the Origin of the Cube Texture" Acta Metallurgica, 1953, Vol 1, pp 598-606.

9. H. Hu: "Texture of Metals," Texture, 1974, Vol 1, pp 233-258.

10. K. H. Abbott: "Review of AMMRC CTR 76-22," Army Materials and Mechanics Research Center, March 18, 1977.

Table I

Chemical Composition of Armor Steel in Weight Percent

Ingot	C	Mn	P	S	Si	[illegible]	Ni	Mo	V	Al	N	O, ppm*
705	0.40	0.59	0.003	0.004	1.06	0.70	5.50	0.44	0.073	0.083	0.004	26
706	0.35	0.62	0.003	0.003	1.15	0.81	5.60	0.51	0.090	0.084	0.005	31
717	0.38	0.63	0.003	0.004	1.27	1.04	5.52	0.51	0.095	0.072	0.004	41

*These oxygen contents were the average value of four determinations on the various hot-rolled plates of each steel. For Ingot 705, an initial analysis of one of the plates showed an oxygen content of 405 ppm, which was excluded in averaging.

Table II

Hardness of the Plates Rolled to Various Reductions at 1500°F then Quenched and Tempered

Ingot No.	Plate Identification	Rolling Reduction at 1500°F, %	Hardness, R_C L	Hardness, R_C T	Average R_C
705	A	60	56.5	55.4	56.0
	B	70	56.5	55.1	55.8
	C	80	55.9	54.3	55.1
	D	90	55.9	54.6	55.3
706	A	60	55.9	55.6	55.8
	B	70	56.5	55.6	56.1
	C	80	[illegible]	54.9	55.6
	D	90	[illegible]	55.1	55.3
717	B	70	54.9	54.6	54.8
	C	80	54.9	54.6	54.8
	D	90	55.1	54.1	54.6

Table III

Ballistic Performance of the Plates Rolled to Various Reductions at 1500°F, then Quenched and Tempered Texture Type (112) + (111)

Ingot No.	Plate Identification	Rolling Reduction, %	Texture Intensity*	Test Plate Thickness, in.	Hardness, R_C	V_{50} Ballistic Limit, fps**
705	A	60	3.75	0.460	56.0	Increasing ↓
	B	70	5.10	0.465	55.8	
	C	80	6.60	0.498	55.1	
	D	90	9.05	0.491	55.3	
706	A	60	3.85	0.495	55.8	Increasing ↓
	B	70	5.00	0.494	56.1	
	C	80	6.00	0.495	55.6	
	D	90	7.85	0.495	55.3	
717	B	70	4.45	0.496	54.8	Increasing ↓
	C	80	6.10	0.498	54.8	
	D	90	7.20	0.500	54.6	

*Based on the intensity maxima of the (110) pole figure.

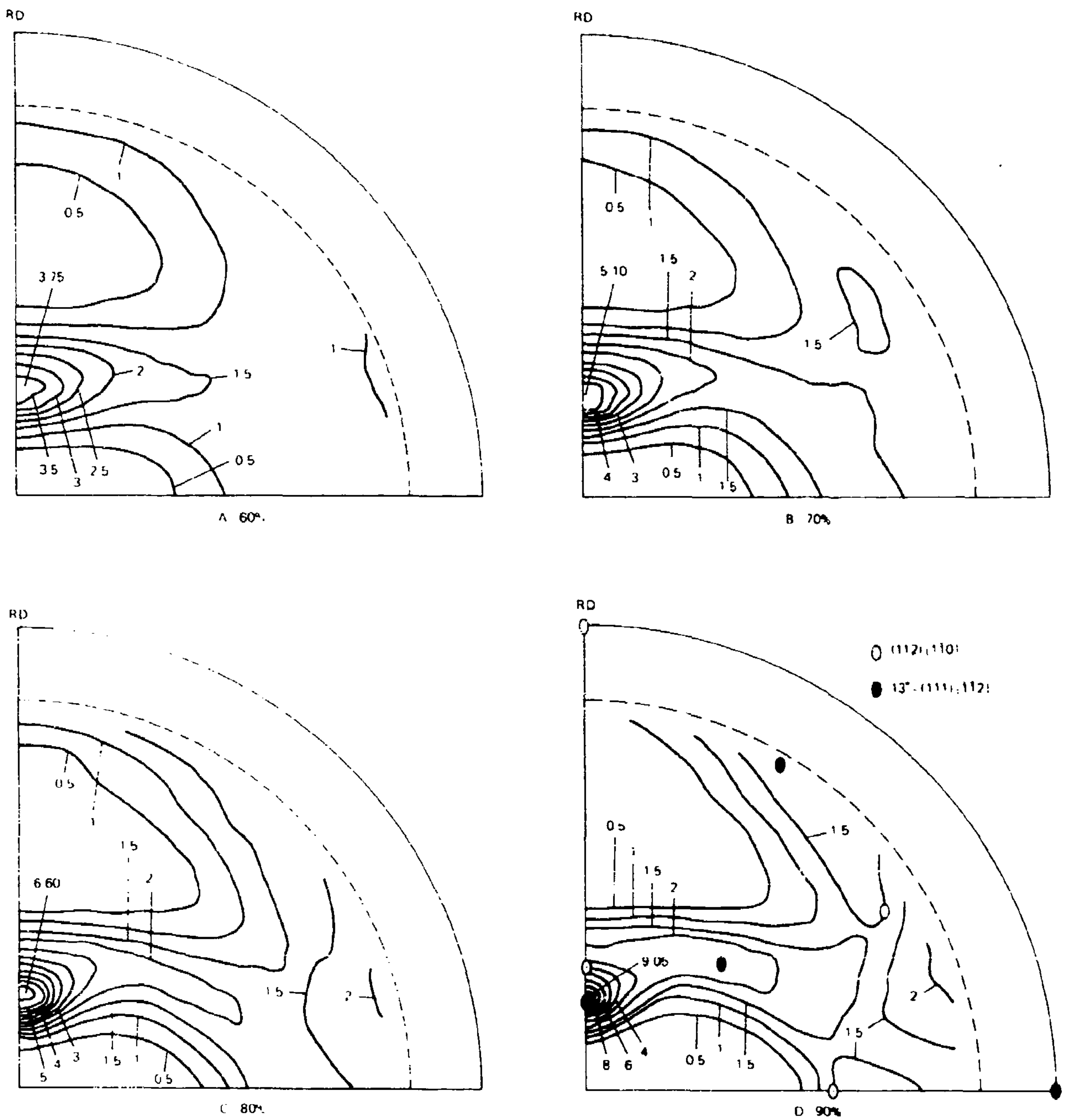
**With 0.50 caliber projectiles at 0° obliquity.

Table IV

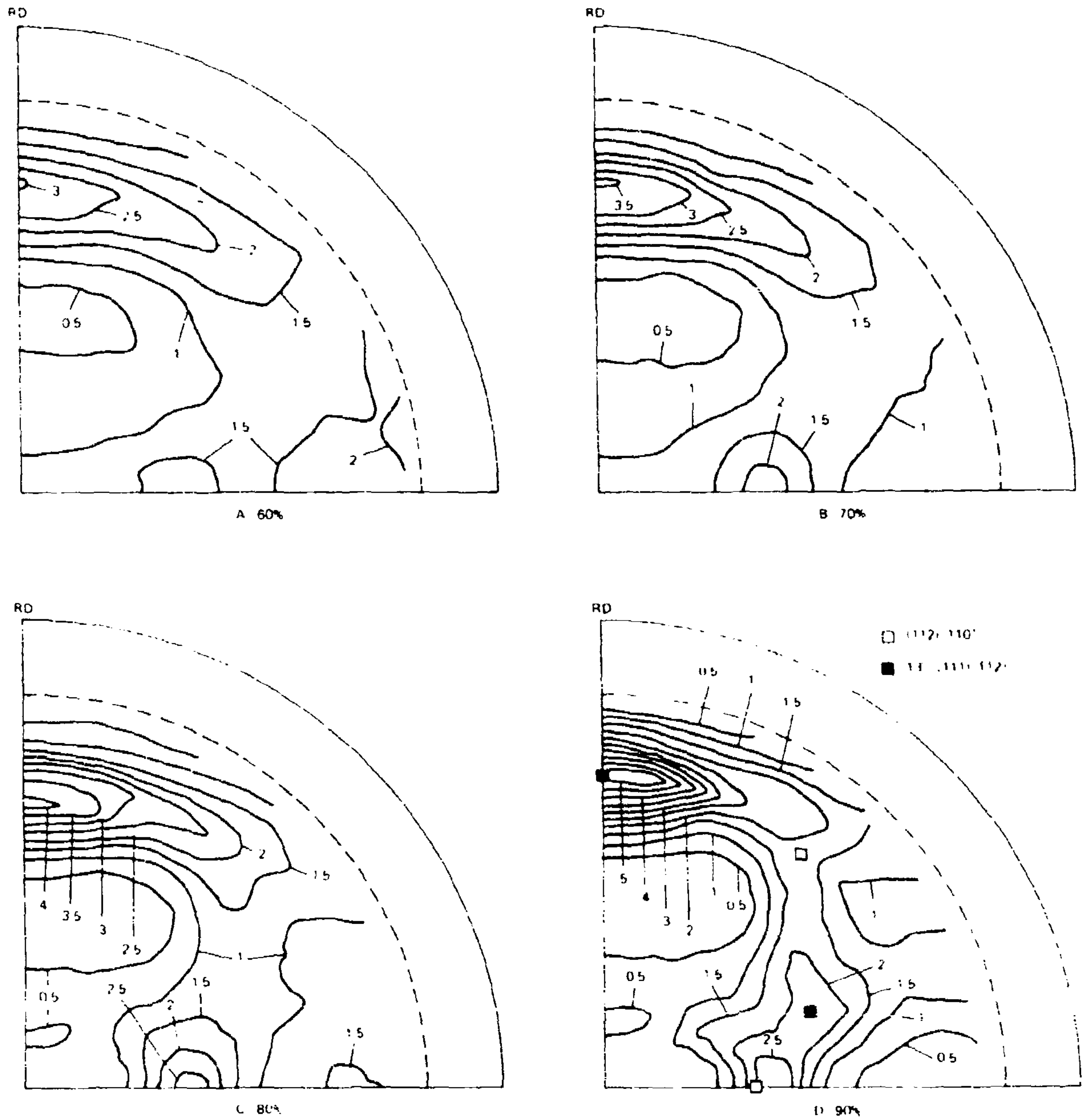
Summary of Information on Exploratory Specimens Cross-Rolled to Various Reductions at 1500°F then Quenched and Tempered

Specimen Identification	Cross-Rolling Reduction, %	Texture Type	Texture Intensity*	Hardness, R_C Section // to RD_1	RD_2	Average
PX-1	60	(223) or 11° from (111)	2.10	57.0	56.7	56.8
PX-2	70		2.60	57.0	56.7	56.8
PX-3	80		2.70	56.7	56.7	56.7
PX-4	90		2.80	57.4	57.4	57.4

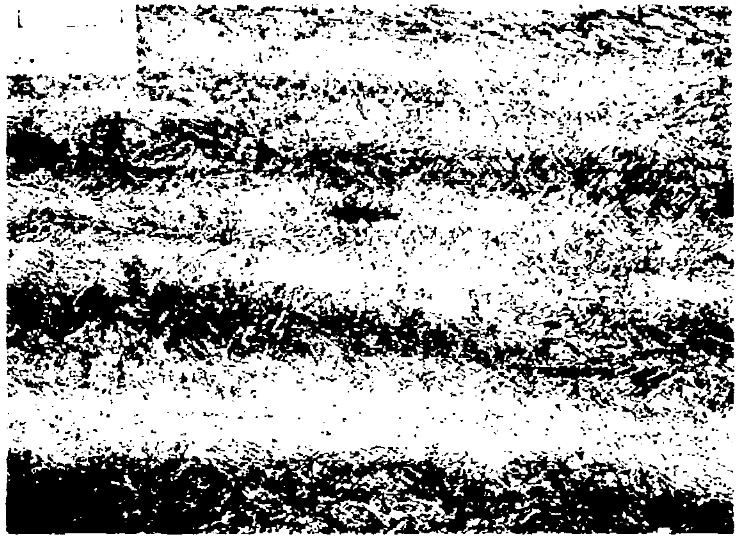
*Based on the intensity maxima of the (110) pole figure.



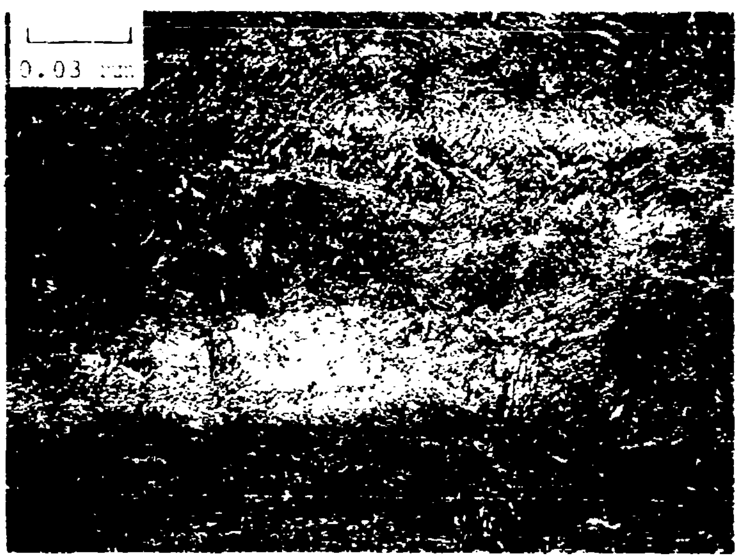
(110) POLE FIGURES OF THE PLATES ROLLED TO VARIOUS REDUCTIONS AT 1500°F THEN QUENCHED AND TEMPERED (INGOT 705)



(200) POLE FIGURES OF THE PLATES ROLLED TO VARIOUS REDUCTIONS AT 1500°F THEN QUENCHED AND TEMPERED (INGOT 705)



A. Longitudinal



B. Transverse

Microstructure of the plate rolled 60 percent at 1500°F then quenched and tempered (Ingot 705). Nital etch. X500.

VP 680
VP 681

Figure 3

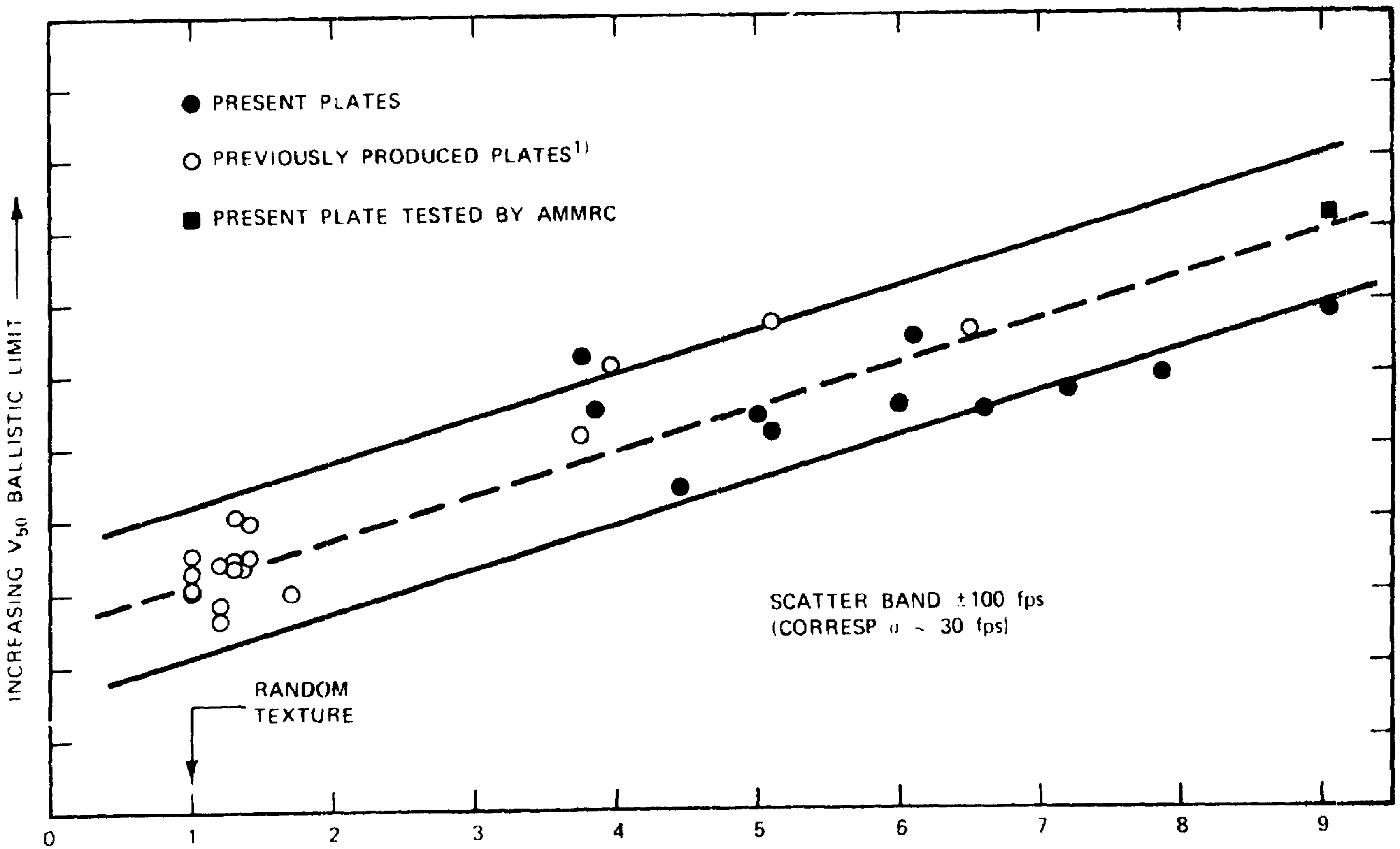
A. Longitudinal

B. Transverse

Microstructure of the plate rolled 90 percent at 1500°F then quenched and tempered (Ingot 705). Nital etch. X500.

VP 686
VP 687

Figure 4

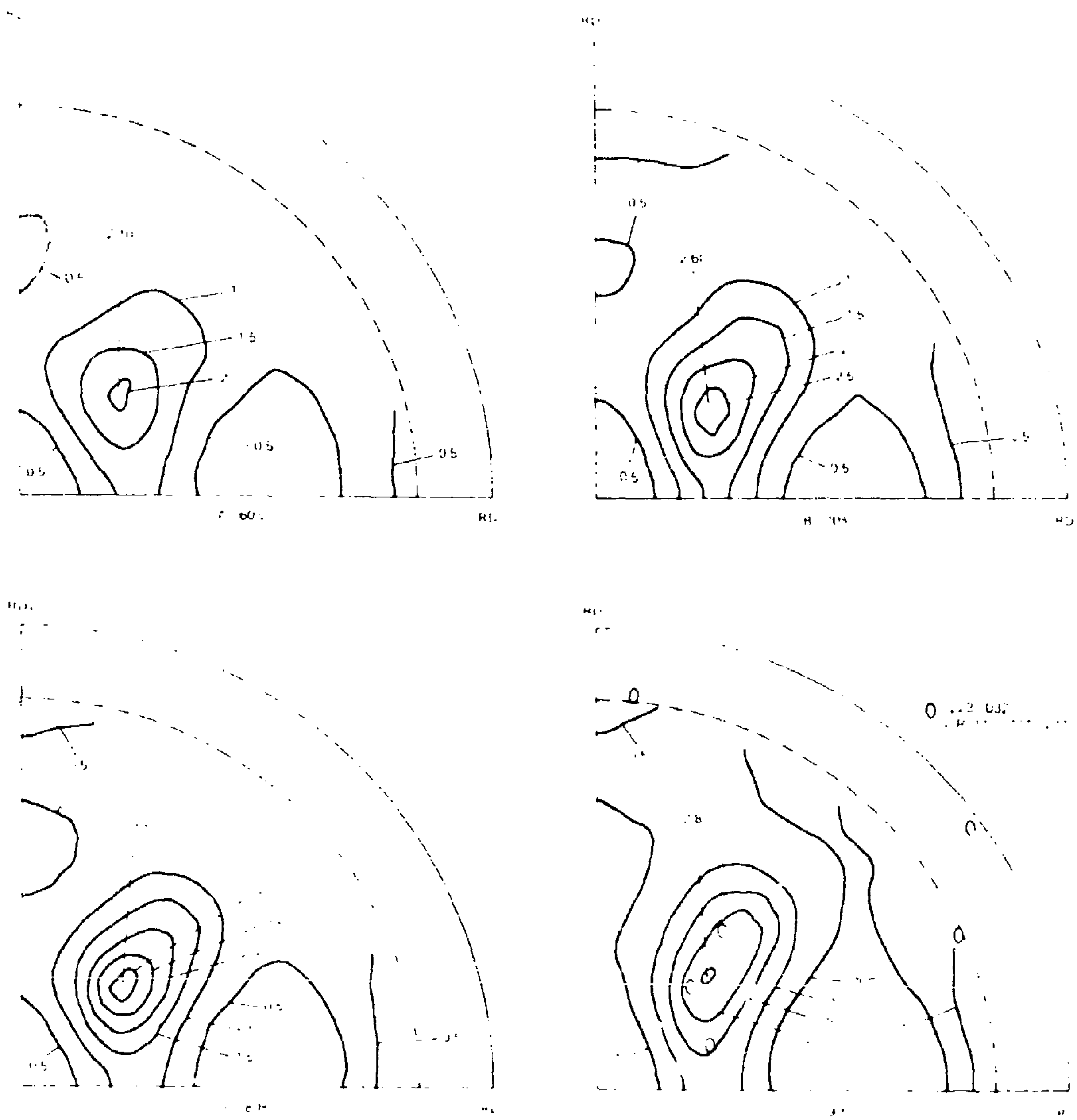


CORRELATION OF THE BALLISTIC LIMIT WITH THE INTENSITY OF (112) + (111) TEXTURE

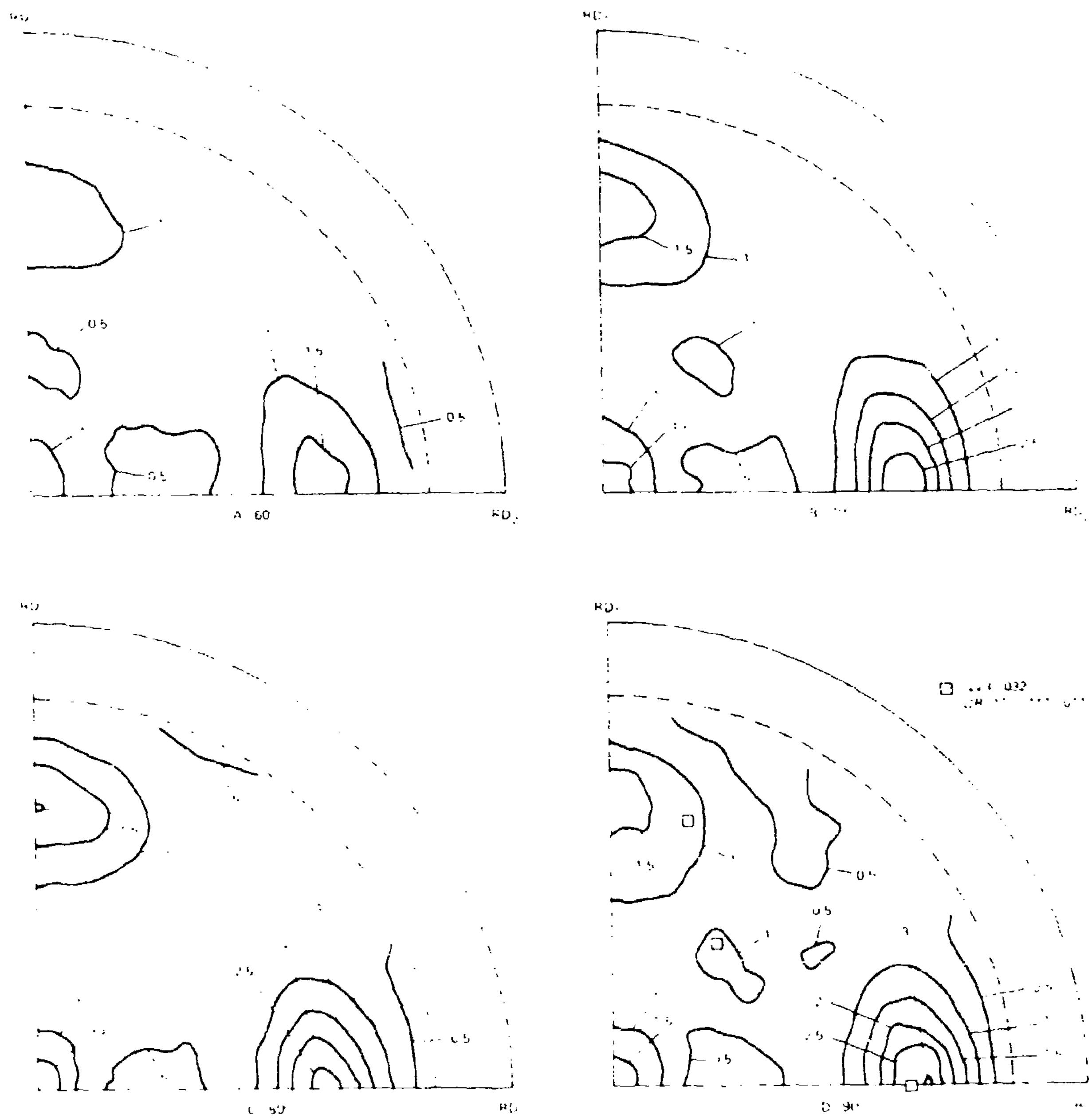
RL 61 127

76-H-037(061 1)

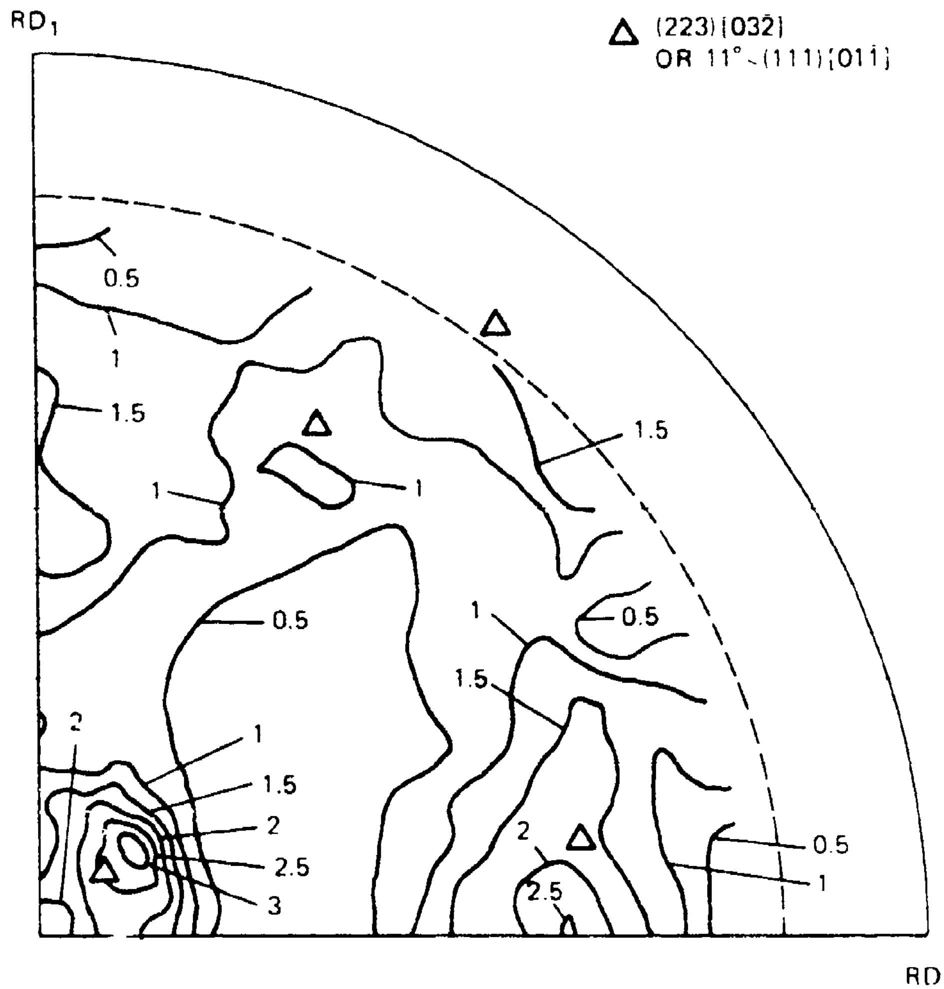
Figure 5



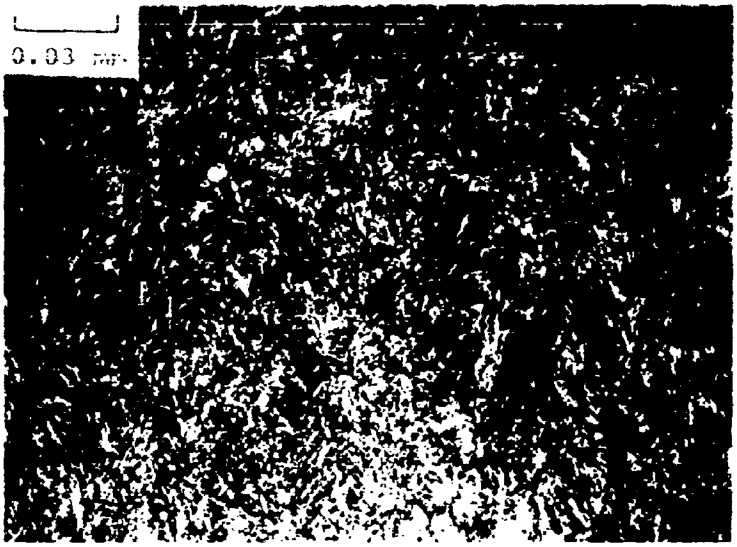
(110) POLE FIGURES OF THE SPECIMENS CROSS-ROLLED TO VARIOUS REDUCTIONS AT 1500°F THEN QUENCHED AND TEMPERED



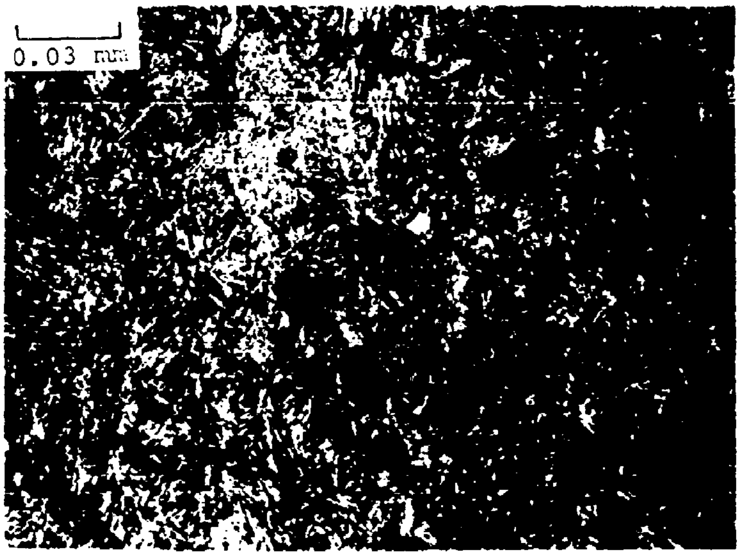
(200) POLE FIGURES OF THE SPECIMENS CROSS-ROLLED TO VARIOUS REDUCTIONS AT 1500°F THEN QUENCHED AND TEMPERED



(222) POLE FIGURE OF THE SPECIMEN CROSS-ROLLED 90% AT 1500°F THEN QUENCHED AND TEMPERED



A. Sectioned perpendicular to the first rolling direction (RD_1)

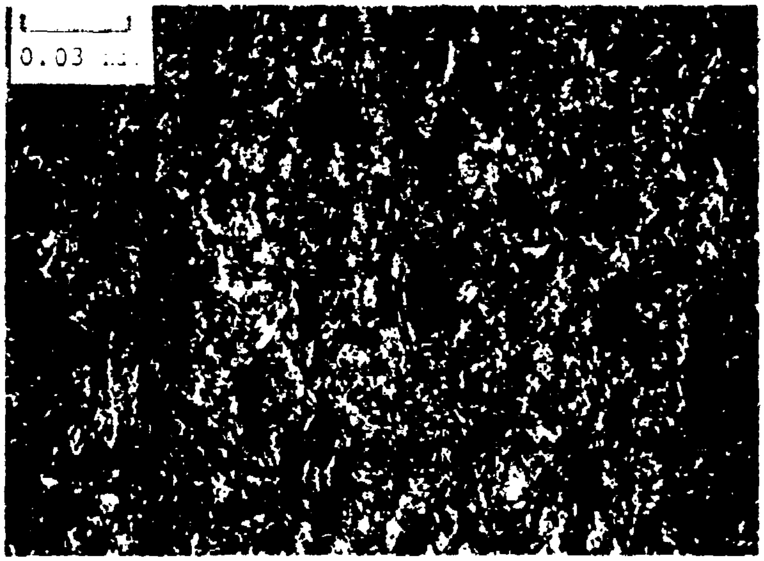


B. Sectioned perpendicular to the second rolling direction (RD_2)

Microstructure of the specimen cross-rolled 60 percent at 1500°F then quenched and tempered. Nital etch. X500.

VP 704
VP 705

Figure 9



A. Sectioned perpendicular to the first rolling direction (RD_1)

B. Sectioned perpendicular to the second rolling direction (RD_2)

Microstructure of the specimen cross-rolled 90 percent at 1500°F then quenched and tempered. Nital etch. X500.

VP 710
VP 711

Appendix A

The sixty-six 6- by 12- by ∿1/2-inch plates that were shipped to the Army Materials and Mechanics Research Center for ballistic testing and other mechanical or metallographic studies by the Army were identified and summarized as follows:

Ingot No.	Hot-Rolling Reduction, %	Plate Identifications	
705	60	A1	A2
		A1	A2
			A2 (0.47 in.)
	70	B1	B2
		B1	B2
		B1	B2
		B1	
	80	C1	C2
		C1	C2
			C2
			C2
	90	D1	D2
		D1	D2
		D1	D2 (0.25 in.)*
			D2 (0.25 in.)*
706	60	A1	A2
		A1	A2
			A2
	70	B1	B2
		B1	B2
		B1	B2
		B1	
	80	C1 (0.47 in.)	C2
			C2
			C2
	90	D1	D2
		D1	D2
		D1	D2 (0.47 in.)
		D1 (0.25 in.)*	

Ingot No.	Hot-Rolling Reduction, %	Plate Identifications	
717	70		B2
	80	C1	C2
		C1	C2 (0.47 in.)
		C1	
	90	D1	D2
		D1	D2
		D1	D2
		D1	D2
		D1	D2 (0.25 in.)*
		D1	D2 (0.25 in.)*

*Plates ground to 1/4 inch thickness by special request of AMMRC.

Notes to Identification Codes: The letters A, B, C, and D indicate the rolling reductions. These letters also indicate the relative locations of the ingot, D being the bottom portion of the ingot. The numbers 1 and 2 indicate the two halves of the ingot after preliminary rolling to intermediate thicknesses and cutting longitudinally along the centerline of the slab width. Individual plates from the same heat and the same rolling reduction are not distinguished among themselves otherwise.

These 66 plates plus 11 plates ballistically tested at the U. S. Steel Research Laboratory make a total of 77 plates produced under the present contract. The 11 plates used for ballistic testing at U. S. Steel consisted of one plate for each rolling reduction from each of the three ingots, except that no plate was made by rolling to 60 percent reduction from the third ingot (No. 717).

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Texture

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The present research program consisted of two parts. (1) To produce a number of 6- by 12- by ~1/2-inch armor plates having strong (112) + (111) texture with various degrees of intensity by the thermomechanical processing treatments of essentially the same medium-carbon, 5Ni-Si-Cu-Mo-V steels used previously, and to establish the reproducibility of texture, microstructure, hardness, and ballistic performance of these steel armor plates. Results

indicated that the reproducibility of the structure and properties of these steel armor plates was excellent. The ballistic limit increased with the texture intensity in nearly the same manner as observed previously. (2) To explore the possibility of producing a nearly (111) texture with various degrees of intensity in small-size specimens cross-rolled at 1500°F to various reductions then quenched, and to establish a procedure for optimizing this texture in larger 6- by 12- by $\sim$1/2-inch plates. Results indicated that the texture obtained was $\{223\}\langle 032\rangle$, which is about 11 degrees from $\{111\}\langle 011\rangle$, close to that predicted. The development of this texture should be possible in larger 6- by 12- by $\sim$1/2-inch plates that can be used for the testing of mechanical and ballistic properties.

Army Materials and Mechanics Research Center,
Watertown, Massachusetts 02172
STUDIES OF TEXTURE DEVELOPMENT
IN STEEL ARMOR PLATE
Hsun Hu

Final Technical Report AMMRC CTR 77-19, July 1977,
50 pp - illus, DAAG Project 46-77-C-0014
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The present research program consisted of two parts. (1) To produce a number of 6- by 12- by 1/2-inch armor plates having strong {112} + {111} texture with various degrees of intensity by the thermomechanical processing treatments of essentially the same medium-carbon, 5Ni-Si-Cr-Mo-V steels used previously, and to establish the reproducibility of texture, microstructure, hardness, and ballistic performance of these steel armor plates. Results indicated that the reproducibility of the structure and properties of these steel armor plates was excellent. The ballistic limit increased with the texture intensity in nearly the same manner as observed previously. (2) To explore the possibility of producing a nearly {111} texture with various degrees of intensity in small-size specimens cross-rolled at 1500°F to various reductions then quenched, and to establish a procedure for optimizing this texture in larger 6- by 12- by 1/2-inch plates. Results indicated that the texture obtained was {223}⟨012⟩, which is about 11 degrees from {111}⟨011⟩, close to that predicted. The development of this texture should be possible in larger 6- by 12- by 1/2-inch plates that can be used for the testing of mechanical and ballistic properties.

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Key Words

1. Ballistic properties
2. Steel armor
3. Thermomechanical treatment
4. Preferred orientation
5. Retained austenite
6. Texture

I. Hu, Maun
II. Contract DAAG46-77-C-0014
III. AMCMS Code 612105.11.H8400